Abundance And Size Of Dominant Winter-Immigrating Fish Larvae At Two Inlets Into Pamlico Sound, North Carolina

William F. Hettler, Jr.
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Southeast Fisheries Science Center
101 Pivers Island Road
Beaufort, North Carolina, USA 28516-9722

ABSTRACT--Weekly sampling for the larvae of six species of ocean-spawning, estuarine-dependent fishes was conducted from October 1994 to April 1995 inside Oregon Inlet and Ocracoke Inlet, two major inlets into Pamlico Sound, North Carolina. Atlantic menhaden, *Brevoortia tyrannus*, were similar in average density at both inlets; Atlantic croaker, *Micropogonias undulatus*, and summer flounder, *Paralichthys dentatus*, were more abundant at Oregon Inlet; spot, *Leiostomus xanthurus*, pinfish, *Lagodon rhomboides*, and southern flounder, *P. lethostigma*, were more abundant at Ocracoke Inlet. Atlantic croaker were significantly larger at Oregon Inlet at the beginning and end of the ingress season, whereas Atlantic menhaden were significantly smaller at Ocracoke Inlet at the end of the season (ca. 12 mm vs. 27 mm). Abundance data from Oregon and Ocracoke inlets were compared with abundance data collected during the same period at Beaufort Inlet and with data from a previous monthly survey conducted six years earlier at the same stations at Oregon and Ocracoke inlets. Winter temperatures were similar at both inlets, but Ocracoke Inlet was warmer during spring. Oregon Inlet was less saline than Ocracoke Inlet at every sampling event.

Pamlico Sound, the largest barrier island estuary in the United States (5,200 km^2), supports numerous fisheries either indirectly as juvenile habitat or directly as fishing grounds. Major fisheries include species of Clupeidae, Paralicthyidae, and Sciaenidae. Most species of these families spawn in the ocean, after which their larvae pass through inlets before reaching estuarine nurseries. Data on the ingress through inlets of larvae of these species are essential in understanding variability in annual recruitment. The only publication describing the seasonal abundance of fish larvae in inlets to Pamlico Sound was based on once-monthly sampling (Hettler and Barker 1993). Since that study, analysis of a daily sampling experiment at Beaufort Inlet concluded that sampling weekly or more often significantly increases confidence in larval abundance estimates (Hettler et al. 1997) . The objective of my study was to sample weekly at two of the three inlets connecting Pamlico Sound directly to the Atlantic Ocean (Oregon Inlet and Ocracoke Inlet) to compare their relative contribution as larval fish pathways to the marine species nursery grounds in the sound and adjacent tributaries as identified by Epperly and Ross (1986).

METHODS

Oregon Inlet is the only inlet into Pamlico Sound north of Cape Hatteras and lies in the temperate Virginian Province near the southern end of the Labrador Current (Fig. 1). Ocracoke Inlet, the largest inlet in North Carolina and one of two inlets connecting Raleigh Bay (located between Cape Hatteras and Cape Lookout) with Pamlico Sound, lies in the subtropical Carolinian Province. These inlets were sampled for 27 consecutive weeks between October 1994 and April 1995 during the ingress of larvae of six targeted species of fall-winter spawning fishes, five of which contribute 85% of the total commercial fish catch in North Carolina (Miller et al. 1984).

Fig. 1. Study location.

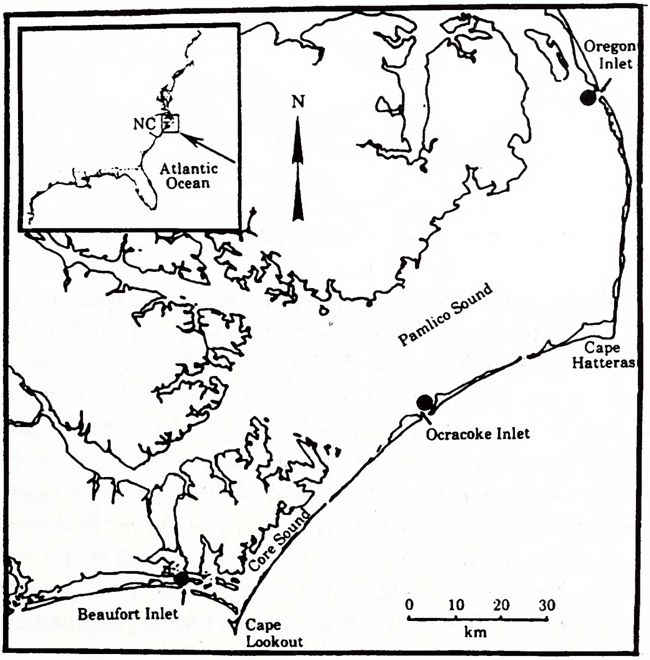
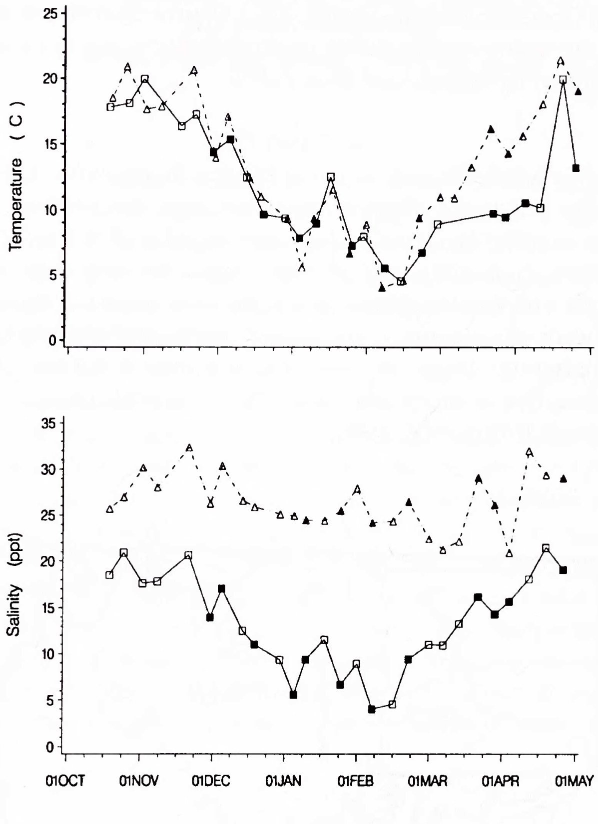


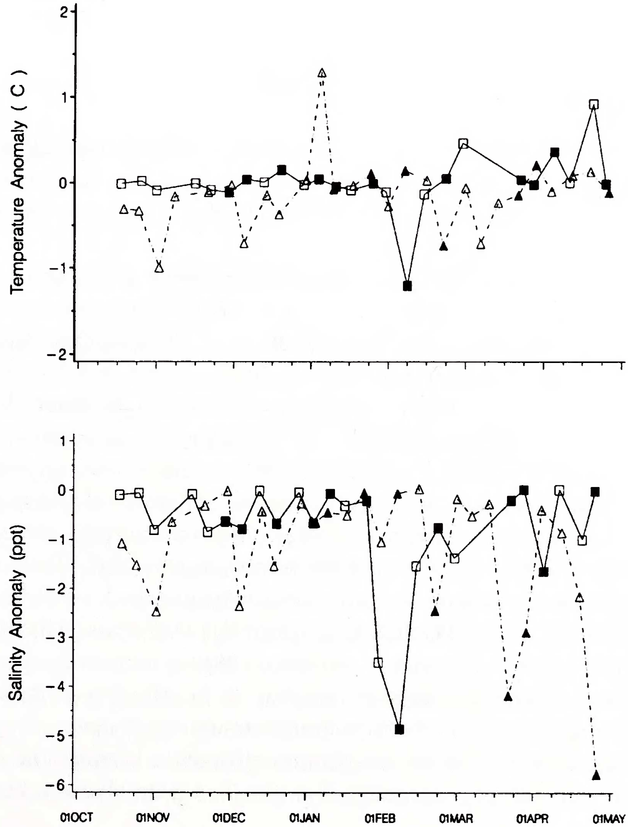
Fig. 2. Mean water column temperature and salinity at Oregon Inlet (solid line, squares) and Ocracoke Inlet (dashed line, triangles), North Carolina, for each weekly sampling trip during the 1994-95 larval fish immigration period. Solid symbols indicate ebb tide samples; open symbols indicate flood tide samples.



Inside each inlet a single sampling station was established in the center of the main flood-tide channel (Oregon Inlet station: 35E 46.3'N, 75E 33.5'W ; Ocracoke Inlet station: 35E 06.4'N, 75E 59.5'W). The deepest water at each station was 7 m and the channel width was about 300 m. Inlets were sampled one night each week on adjacent nights (quasi-synoptic). Each night's sampling consisted of 12 repetitive tows, about 10 minutes apart, with a 0.8-m^2, 800 micron-mesh-net on a 1-m-diameter, sled-mounted, aluminum frame towed at a net speed of 1 m/sec . A tow consisted of actively towing the net in the deepest water along the axis of the channel down to the bottom and back to the surface. Tows were always made into the current. A flow-meter measured the volume of water passing through the net. Each tow took 4 minutes, filtering approximately 200 m^3

of water. Preceding each tow, temperature and salinity casts were taken with a SeaBird 19 CTD and direction of tidal flow was recorded. CTD data were averaged for the entire water column and all tows on a given date (Fig. 2), because the oblique net tows integrated the larval catch from throughout the water column and the vertical distribution of the larvae was unknown. However, the surface and bottom values were compared to show the amount of temperature and salinity stratification in the channel at each station (Fig. 3). As observed from the vessel, the channel currents were flooding on 15 of the 27 dates at Oregon Inlet and on 20 of the 27 dates at Ocracoke Inlet.

Fig. 3. Difference (anomaly) between the surface and the bottom temperature and salinity at Oregon Inlet (solid line, squares) and Ocracoke Inlet (dashed line, triangles), North Carolina, during the 1994-95 larval fish immigration period. Positive values indicate warmer or more saline water at the surface; negative values indicate warmer or more saline at the bottom. Solid symbols indicate ebb tide sampling; open symbols indicate flood tide sampling.



On board the vessel, larvae were preserved in 70% ethyl alcohol. In the laboratory, larvae were sorted by species and counted. Up to 10 larvae of each species from each tow were measured to the nearest 0.1 mm standard length. Larval abundance was calculated as the number per 100 m^3 and plotted as the weekly mean density (± 1 standard error) of the individual tow densities by inlet and date. Lengths were plotted as the mean standard length of up to 120 larvae of each species at each inlet each week (± 1 standard error).

Wilcoxon rank sum tests were used to compare densities of species between inlets. To examine the relative contribution by inlet for each species, the seasonal weekly density by species for Oregon Inlet and Ocracoke Inlet was compared with data collected during the same period in a separate study at Beaufort Inlet (Warlen 1994; S. Warlen, NMFS Beaufort Laboratory, personal communication). For this comparison, it should be recognized that the Beaufort Inlet study results are used as proxy data in the absence of data collected with the same methods as at Oregon and Ocracoke inlets. In the Beaufort study, a 2-m^2, 1000-micron-mesh neuston net was fished passively in the tidal current at the surface. In both studies, however, the data were standardized to densities per unit volume by the use of flow meters.

RESULTS AND DISCUSSION

TEMPERATURE AND SALINITY

The inlets were similar in temperature, except that Ocracoke Inlet warmed at a faster rate after late February than did Oregon Inlet (Fig. 2). During February, when abundance of most larval species was low, temperature at both inlets dropped to less than 5C.

Salinity as high as 33 ppt was observed twice at Ocracoke Inlet, once in late autumn and once in early spring, a time when salinity at Oregon Inlet was about 20 ppt. Salinity at Oregon Inlet was always 5-20 ppt lower than Ocracoke Inlet and in February was as low as 4 ppt. Salinities lower than 10 ppt in Oregon Inlet in combination with low temperatures occurred eight times. The physiological consequences of low salinities and temperatures on ocean-spawned larvae is only partially known. For example, *Brevoortia tyrannus* (Atlantic menhaden) larvae died in laboratory experiments at salinities <5 ppt and temperatures <5 C. In these experiments, however, 50% mortality in <48 hours also occurred at high salinity (30 ppt) and low temperatures (<5 C) (Lewis, 1966). In other laboratory experiments, *Leiostomus xanthurus* (spot) were determined to be more cold sensitive at 10 C than *Micropogonias undulatus* (Atlantic croaker), but test salinities were not given (Hoss et al. 1988). Their study concluded that during severe winters many early arriving larvae in estuaries are killed and that only late arriving larvae survive for recruitment into the fishery.

Twice at each inlet, the temperature difference between the surface and bottom water equaled or exceeded 1 C in the 7-m-deep channel, but generally there was little thermal stratification (Fig. 3). On several occasions the water column was colder at the surface when strong, cold winds were present. On the other hand, salinity was often positively stratified, as much as 6 ppt less saline at the surface. At Oregon Inlet during early February, when there was a 5 ppt difference between the surface and bottom, the surface was 1C colder than the bottom. At this time, the current direction at the surface was ebbing.

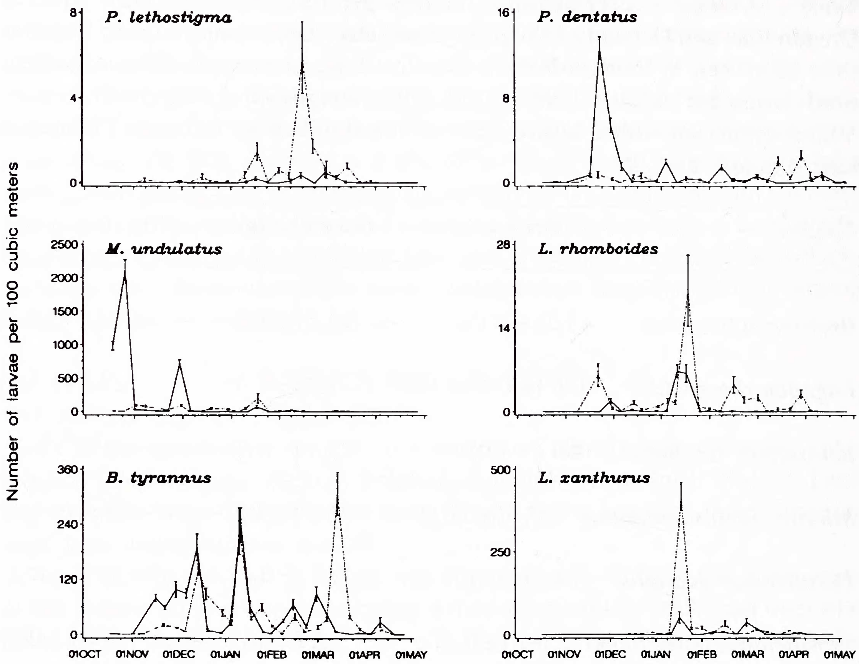
Table 1. Average weekly densities (number per 100 m^3 ± 1 standard error) at Oregon Inlet and Ocracoke Inlet (0.8-m^2 net, this study) compared with Beaufort Inlet (2-m^2 net, S. Warlen, NMFS, Beaufort Laboratory, personal communication) during the October 1994 - April 1995 immigration season (n=27 weeks). Values connected with a dashed line are not significantly different (Wilcoxon rank sum test, a =0.05).

Species	Oregon Inlet	Ocracoke Inlet	Beaufort Inlet
Brevoortia tyrannus	43.2 (± 4.1)-------------	-43.5 (± 4.9)------------	-22.9 (± 8.4)
Lagodon rhomboides	0.6 (± 0.1)	1.7 (± 0.3)	12.4 (± 3.9)
Leiostomus xanthurus	4.4 (± 1.0)	21.1 (" 4.8)-------------	-4.8("18.7)
Micropogonias undulatus	155.5(± 27.1)	26.9 (± 3.9)-----------	-25.7 (± 6.1)
Paralichthys dentatus	1.0 (± 0.2)	0.3 (± 0.1)-------------	-0.3 (± 0.2)
Paralichthys lethostigma	0.1 (± 0.1)	0.5 (± 0.1)	0.8 (± 0.3)

ABUNDANCE

Unlike the other five selected species, Atlantic menhaden were not significantly different in average weekly density at any inlet, although fewer appeared to be caught at Beaufort Inlet during the year (Table 1). Spot were less abundant at Oregon Inlet than the other inlets, but Atlantic croaker were most abundant at Oregon Inlet. Pinfish (*Lagodon rhomboides*) and southern flounder (*P. lethostigma*) were different in density among all inlets. Spot, pinfish, and southern flounder increased in density towards the south, whereas Atlantic croaker and summer flounder decreased, which is the expected pattern based on the known distribution of these species (Fahay 1983). North Carolina is the center of the known spawning range of Atlantic menhaden (Freidland et al. 1996), and similar densities at these inlets is not surprising even though the spawning locations contributing Atlantic menhaden larvae to each inlet is unknown.

Fig. 4. Mean densities of six selected species of fish larvae at Oregon Inlet (solid line) and Ocracoke Inlet (dashed line), North Carolina, during the 1994-95 larval fish immigration period. Error bars equal ± 1 standard error.



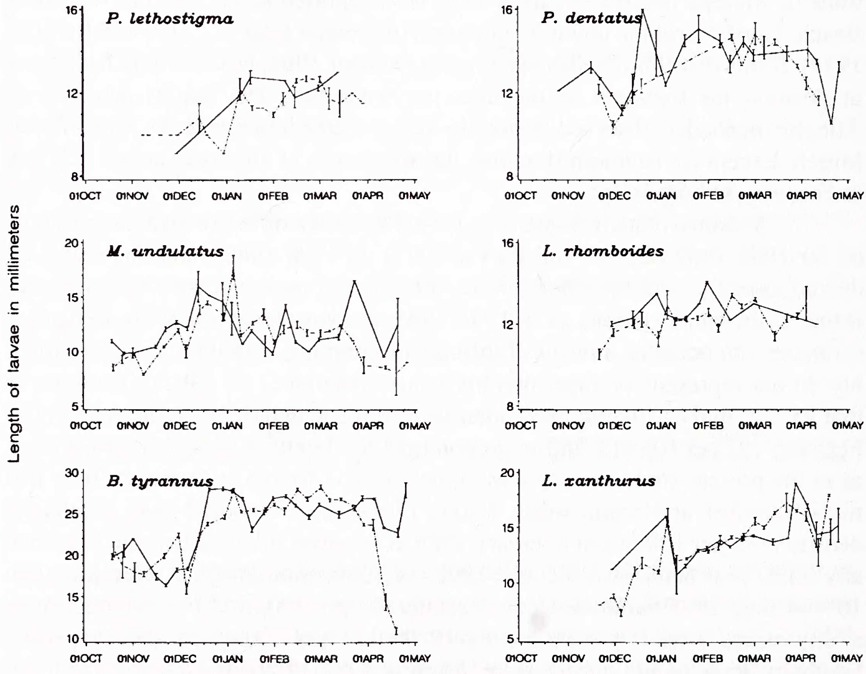
One or more prominent peaks in densities of each species occurred at one or both inlets during the season (Fig. 4). Atlantic croaker were dominant during the early season at Oregon Inlet with a weekly mean density of >2000 per 100 m^3 in late October. In one tow on 29 October 1994, the catch density was 3000 larvae per 100 m^3. Another pulse of Atlantic croaker entered Oregon Inlet in early December, a week after summer flounder peaked in density at that inlet. Peak summer flounder densities at Oregon Inlet preceded the period of peak recruitment into Ocracoke by more than 3 months. Summer flounder were found to peak in Beaufort Inlet in February (Burke et al. 1991). The peak abundance of Atlantic croaker and summer flounder larvae observed early in the season at Oregon Inlet compared to the two inlets south of Cape Hatteras, suggests that these species are coming from spawning areas that have cross-shelf transport routes north of Cape Hatteras. Southern flounder, which were not abundant at Oregon Inlet, peaked at Ocracoke Inlet in mid-February, the same period as reported earlier for Beaufort Inlet by Burke et al. (1991). Gulf flounder (P. albigutta), an abundant paralichyid south of Cape Hatteras, were not caught at Oregon Inlet and therefore are not considered further. The largest numbers of pinfish were caught at both inlets in mid-January. Spot also were most abundant in mid-January, but only at Ocracoke. Early in the season Atlantic menhaden were more abundant at Oregon Inlet than at Ocracoke, but both inlets had high numbers in mid-December and mid-January. The high densities of Atlantic menhaden at Oregon Inlet in November, a month before significant ingress into Ocracoke, suggests that spawning or favorable cross-shelf transport currents supplying these larvae took place north of Cape Hatteras. In early October, concentrations of Atlantic menhaden larvae have been reported as far south as Currituck Beach, North Carolina, about 60 km north of Oregon Inlet (Kendall and Reintjes 1974). If this distribution also occurred in October 1994, larvae would have been in position for transport to the inlet by November. The largest densities of Atlantic menhaden observed during the season came into Ocracoke Inlet in mid-March. Except for southern flounder, the abundance of all other species was low in February at both inlets.

Seasonal density patterns in 1994-1995 were different than those reported for 1988-1989 (Hettler and Barker 1993). In 1988-1989, sampling was conducted monthly with the same 0.8-m^2, 800 micron-mesh-net on a 1-m-diameter frame at the same stations as in 1994-1995. Because large variablity in density estimates can occur as a result of infrequent sampling, monthly densities probably do not represent average monthly values (Hettler et al. 1997). However, in that earlier study, Atlantic menhaden were most abundant at Ocracoke Inlet in February (92 per 100 m^3) and at Oregon Inlet in March (222 per 100 m^3), whereas in the present study density was highest in mid-March at Ocracoke Inlet and mid-December at Oregon Inlet. Warlen (1994) also recorded peak menhaden density (130 per 100 m^3) in February 1989 at Beaufort Inlet, earlier that year than any other year between 1986 and 1992. In 1989, spot densities were less than 10% of their 1995 values at Ocracoke Inlet (27 per 100 m^3). Flounder densities at any month were low during 1988-1989 (< 1 per 100m^3) for either species. Southern flounder and pinfish were taken in 1988-1989 only at Ocracoke Inlet.

SIZE

For all species, significant differences in body size occurred between inlets on many sampling dates (Fig. 5). Average lengths of Atlantic menhaden at Oregon Inlet decreased in length during November and then rapidly increased by about 10 mm in mid-December. Increasing density and decreasing size of Atlantic menhaden larvae in early November at Oregon Inlet indicated that spawning schools moving south for the winter were approaching the vicinity of the inlet. At Ocracoke larvae increased from about 17 mm in early December to 27 mm by early January. During the remainder of winter, 25-28 mm Atlantic menhaden were caught at both inlets until the end of the season at Ocracoke when the size of larvae decreased to as small as 10 mm. These small menhaden in April probably resulted from spawning south of Ocracoke Inlet by northerly-moving adults. Small Atlantic menhaden were not collected at Oregon Inlet or at Beaufort Inlet in April.

Fig. 5. Mean standard length of six selected species of fish larvae at Oregon Inlet (solid line) and Ocracoke Inlet (dashed line), North Carolina, during the 1994-95 larval fish immigration period. Error bars equal ± 1 standard error.



Atlantic croaker increased >50% in length at both inlets between late October and late December. Spawning of Atlantic croaker near Cape Hatteras begins at least by early September, peaks in October, and is reduced by late December with perhaps another peak in the spring (Morse 1980). Near Beaufort Inlet, in Onslow Bay, Atlantic croaker were reported to spawn between mid September and late February, with the majority of spawning between late September through November (Warlen 1982). Evidence of summer spawning was presented by Hettler and Barker (1993) who caught 7 mm Atlantic croaker at both inlets in late August 1989. Atlantic croaker this size are probably about 30-days old (Warlen 1982). In April at Ocracoke Inlet, the size of croaker dropped to less than 10 mm due possibly to inshore spawning. The corresponding density data, however, did not indicate the arrival of significant numbers of newly spawned larvae.

Spot increased in length about 2 mm per month after early January and were nearly identical in size at both inlets. At Oregon Inlet no further increase in length was noted until mid-March, when a few early juveniles (>17 mm) were caught. It is difficult to determine if these juveniles had just entered following ocean transport, or were established residents in the inlet or nearby estuary. Juvenile spot (20-26 mm) have been collected in that inlet in May and June 1989 (Hettler and Barker 1993). Spot size data before January and after late March are probably not useful, as few larvae were caught.

The mean lengths of pinfish and both species of flounders increased during the sampling period. Pinfish were typically about 1 mm smaller at Ocracoke than at Oregon Inlet and showed a slight increase in average size at both inlets from December to February. After January, few pinfish were caught at Oregon Inlet. The average lengths of both species of flounder at both inlets increased about 2 mm from December to February. In mid-March at Ocracoke when densities of southern flounder were highest, this species was about 13 mm. When summer flounder peaked in density at Oregon Inlet in mid-December, they also averaged 13 mm.

CONCLUSIONS

From these quasi-synoptic weekly abundance and size estimates of the winter-immigrating marine fish larvae at two major inlets to Pamlico Sound, it appears that Oregon Inlet imported larger-sized individuals and higher densities of Atlantic menhaden, Atlantic croaker, and summer flounder (important commercial species) significantly earlier than at Ocracoke. In winters with mild temperatures, cohorts of older, larger larvae that establish in the nursery areas within Pamlico Sound early in the season may have a survival advantage over cohorts of larvae entering later through either inlet; in severe winters the converse would apply as inferred by Hoss et al. (1988).

The relative value of each inlet as a larval pathway for future juvenile production and recruitment into the fisheries cannot be extrapolated from these data without comparing analyses of the daily age structure of immigrating larvae with juveniles emigrating Pamlico Sound nurseries. Towards this goal, larval specimens furnished from this study are now undergoing age and growth analyses: Atlantic menhaden (J. Rice, North Carolina State University); Atlantic croaker and spot (C. Jones, Old Dominion University). In the mean time, the density data provided above should be useful in evaluating the effects of any future anthropogenic modifications (e.g., jetties) to Oregon or Ocracoke inlets on immigrating fish larvae.

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